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REPORT 1878-9

REPORT
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THE OHIO STATE UNIVERSITY RESEARCH FOUNDATION
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Sponsor	National Aeronautics and Space Administration Goddard Space Flight Center Glen Dale Road Greenbelt, Maryland 20771
Contract Number	NAS5-9507
Investigation of	Tracking, Receiving, Recording and Analysis of Data from Echo Satellite
Subject of Report	The Long Term Autocorrelation Functions of Echo Reflected Signals
Submitted by	Stephen L. Zolnay Antenna Laboratory Department of Electrical Engineering
Date	31 December 1964

ABSTRACT

This report presents the long term (time delays in excess of 100 seconds) autocorrelation functions of Echo (I and II) reflected signals. These ACF's are analyzed for possible long term periodicity in the received signal. A periodicity on the order of 100 seconds has been observed in an earlier analysis of Echo II reflected signals. In this analysis, however, no such periodicity has been observed. Several possible reasons are presented for these findings that differ from the earlier ones. Recommendations are also made for obtaining more significant results about the possible rotation rate of the Echo satellites.

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THE LONG TERM AUTOCORRELATION FUNCTIONS OF ECHO REFLECTED SIGNALS

I. INTRODUCTION

There is but one autocorrelation function, ACF, of a given function, f(t); ACF is defined as

$$\phi(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} f(t)\, f(t+\tau) dt, \tag{1}$$

where τ is the time delay by which f(t) is shifted relative to itself, and T is the sample length taken from f(t). Ideally T should be infinite; practically T is very much finite. Furthermore, in practice the indicated limiting process is neglected. Thus, instead of the exact value of ACF given in Eq. (1), in practical situations one usually obtains some statistical estimate of it. Further, it is convenient to divide the statistical estimates of the ACF according to the length of T from which they were prepared. ACF's prepared from 30-sec-long samples (with corresponding maximum time delays, $\tau_{max} \doteq 3$ sec) were called short-term ACF's. The ACF's presented in this report were prepared from 200-sec or longer sample lengths and $\tau_{max} = T$. Hence the descriptive name long-term.

The function f(t) was the detector output in the receiving system of the Satellite Communications Center of the Antenna Laboratory, The Ohio State University, Columbus, Ohio. This output directly corresponds to the instantaneous value of the received power. The received signal was cw at 2260 mc/sec; it originated from the Space Communications Facility of Collins Radio Company at Dallas, Texas; and it was reflected by the orbiting Echo (I and II) satellites. Five Echo II revolutions were selected for analysis: 2626, 2653, 2816, 3040, and 3483; these are representative of data collected on revolutions 2000 - 3500. Two Echo I revolutions are included for comparison: 18,166 and 18,966. These were selected from passes which occurred during the same time as the five Echo II revolutions.

The purpose of this report is to present the long-term ACF of Echo-reflected signals and to analyze these in order to ascertain possible long-term periodicity in the received signal. The pertinent points in the reduction of data will be discussed; more detailed description has been given elsewhere.[1] Descriptions of the receiving and transmitting sites are also available.[2,3]

II. DISCUSSION

It is an established fact that the ACF of a periodic function is periodic. If the function f(t) in Eq. (1) contains a periodic component varying with angular frequency, ω_0, then for very long T the ACF will also contain a component varying at ω_0. This can be readily verified by letting $f(t) = \sin \omega t$ in Eq. (1), resulting in an ACF which is proportional to $\cos \omega\tau$. This periodicity is also present for periodic functions which are not as smoothly varying as the sine function. Consider, for example, a function which is mostly randomly varying but which has a fixed value for some short time interval and these fixed values occur, say, 100 seconds apart. The ACF of such a function would have peaks at $\tau = 0$, 100, 200, ... etc; and the time between peaks, or values of high correlation would be the same 100 sec as in the original function. In this sense the ACF of such a function would also be periodic.

This search for periodicty in the Echo reflected signals originated with observation of early telemetry transmissions from the beacons on Echo II. There are two beacons mounted on the equator of this satellite which operate on slightly different frequencies. It has been observed that transmissions from the beacons fade out alternately and periodically. From this fact and from the knowledge of the location of the transmitters and the transmitting patterns of the antennas, a rotational period of approximately 100 seconds has been calculated for Echo II. It is not known whether Echo I is rotating. Another phenomenon, independent of beacon transmission, which has been repeatedly observed at this laboratory can be readily explained by postulating that Echo II is rotating. While tracking Echo II it has been observed that the amplitude scintillation rate, which is normally about 10 maxima and minima per second, slowed down considerably to one or less maximum and minimum per second. The scintillations and their rate have been explained in terms of the doppler frequencies associated with a moving rough surface.[4] Very slow fades or few or no scintillations should then correspond to no Doppler shift. It is easy to see that the no Doppler shift condition corresponds to viewing the rotating sphere at an angle which is small when measured from the axis of rotation. The problem of determining the orientation of the axis of rotation can be solved by considering the mechanics of rotating bodies in a gravitational field. For the purposes of this report it is sufficient to state that this axis is most likely stabilized in space. Thus, it would be possible for an observer to see the satellite, at least some time, along its axis of rotation. A sample of the recording proportional to the received signal strength is shown in Fig. 1. To date, the only explanation found for the marked chang in fading rate seen in this recording is that the satellite was observed in a direction which is close to the orientation of its axis of rotation at the time the very slow fades occurred. Thus, having two independent arguments for the rotation of Echo II (telemetry data and fading rates), it was expected that the long-term ACF would be a means of measuring the rotation rate. This investigation was successful with monostatic signals.[5] In this report the investigation is extended to signals reflected bistatically.

III. EXPERIMENTAL DATA

The output of the detector was recorded on a magnetic tape and on a paper chart (see Fig. 1). From the magnetic tape recording a high-speed oscillographic chart was prepared which included the data taken during the pass and the calibration of the receiver and detector. The calibration was plotted and sufficient points from the graph were obtained. Using these points a tenth-order polynomial approximation was made to the calibration curve. The coefficients of the polynomial were used to remove the nonlinearities from the data that were caused by the receiver and detector. The oscillograph was sampled five times per second and a number ranging from 0 - 100 was assigned to the deflection caused by the signal. These points were transferred to punch-cards and IBM 7094 was used to compute the statistical estimate of the ACF. More details of the data reduction and the computer program for the ACF is given in Reference 1.

The output of the computer was plotted; these graphs are shown in Figs. 3-9. All the graphs are normalized to unity and they are all zero for τ_{max}. Since τ_{max} was equal to T, it follows that the ACF approaches zero as $\tau \rightarrow \tau_{max}$. Since some of the sample lengths were only about 200 seconds, it was decided to let $\tau_{max} \rightarrow T$: the resulting triangular function was removed from the ACF's. The procedure is illustrated in Fig. 2. Figure 2a shows the ACF of f(t) where f(t) = 1 for $0 \leq t \leq 1$, and f(t) = 0 elsewhere. Figure 2b is the same as Fig. 2a except the amplitude of f(t) is randomly varying. In Fig. 2c $\phi_a(\tau)$ and $\phi_b(\tau)$ are plotted to the same scale. The values of ϕ are read at points p_i and the value of $\phi_b(\tau)$ is divided by $\phi_a(\tau)$. The result is the right-hand plot in Fig. 2c, in which it is seen that the triangular function has been effectively removed. Since ϕ_a converges to ϕ_b as $\tau \rightarrow \tau_{max}$, little attention should be paid to the corrected $\phi(\tau)$ plot in the immediate vicinity of τ_{max}. This method of correcting the ACF for the superimposed triangular function has been applied to Figs. 3-9. The corrected ACF's are shown in Figs. 10-16.

The long-term ACF's shown in Figs. 3-9, and the adjusted ones shown in Figs. 10-16, were examined for periodicity. It can be said that none of the figures show any apparent periodicity that could be correlated with the claimed 100-second rotational period or with any multiple or submultiple of that period. This observation is consistently true for Echo I and Echo II data. The apparent lack of this periodicity however, does not contradict earlier findings.[5] The data utilized in this report were different from the data on which the earlier findings were based in at least two respects: the sample length was considerably shorter and the reflection at the satellites was bistatic (maximum bistatic angles were on the order of 100 degrees). The possibility that Echo II has stopped rotating since the last long-term ACF analysis, or that at least its rotational rate has changed significantly, should not be excluded from consideration in evaluating these ACF's. To establish the existence of the possible rotation of Echo II and to ascertain the rotational rate with statistically significant accuracy, it is necessary to obtain monostatically reflected signals that are uninterrupted for ten times the duration of one rotational period; in the present case this requirement means several 15-minute periods of uninterrupted signal strength recording.

IV. SUMMARY

The purpose of this report is to present the long-term autocorrelation function of Echo-reflected signals and to analyze these in order to ascertain possible long-term periodicity in the received signals. Accordingly, data collected on five Echo II revolutions were analyzed; these data were representative of all data collected on recent Echo II revolutions (2000 - 3500). Data collected on two Echo I revolutions have also been included. These were selected from the same period during which the Echo II revolutions occurred. The data corresponding to the received signal level was digitized at the rate of five samples per second, linearized, and the ACF was obtained from the linearized data with the aid of a computer. The computer outputs were graphed and further processed for easy evaluation of any periodicity in the prepared ACF's. No apparent periodicity has been found in these ACF's. This finding, however, does not contradict earlier ones[5] because of (a) different sample lengths, (b) different reflecting configurations at the satellites, and (c) the possibility of changes in the rotation rate of Echo II since the earlier ACF analysis. Recommendations are made for obtaining statistically significant results about the possible rotation rate of the Echo satellites.

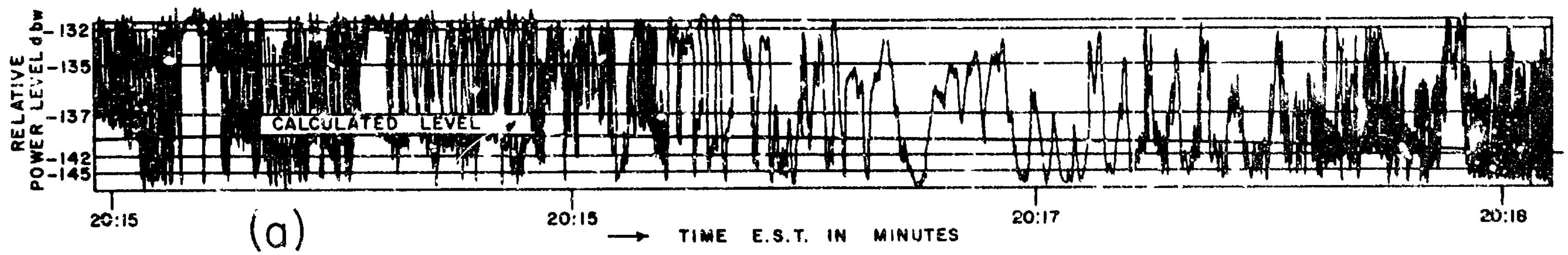

Fig. 1. Sample of received signal strength recording Echo II revolution 2653.

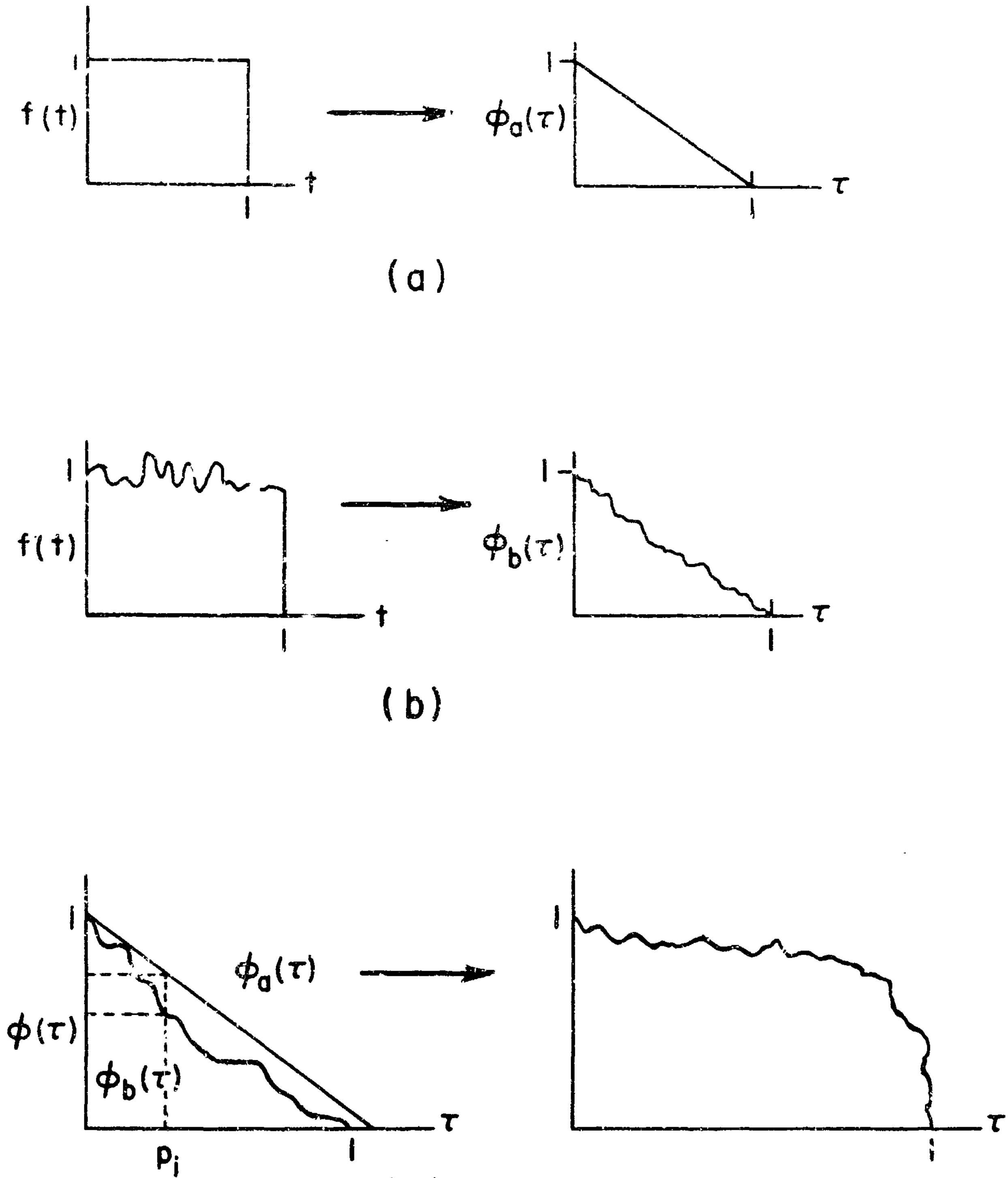

Fig. 2. Illustration of the procedure of removing the triangular function superimposed on the ACF when $\tau_{max} = T$.

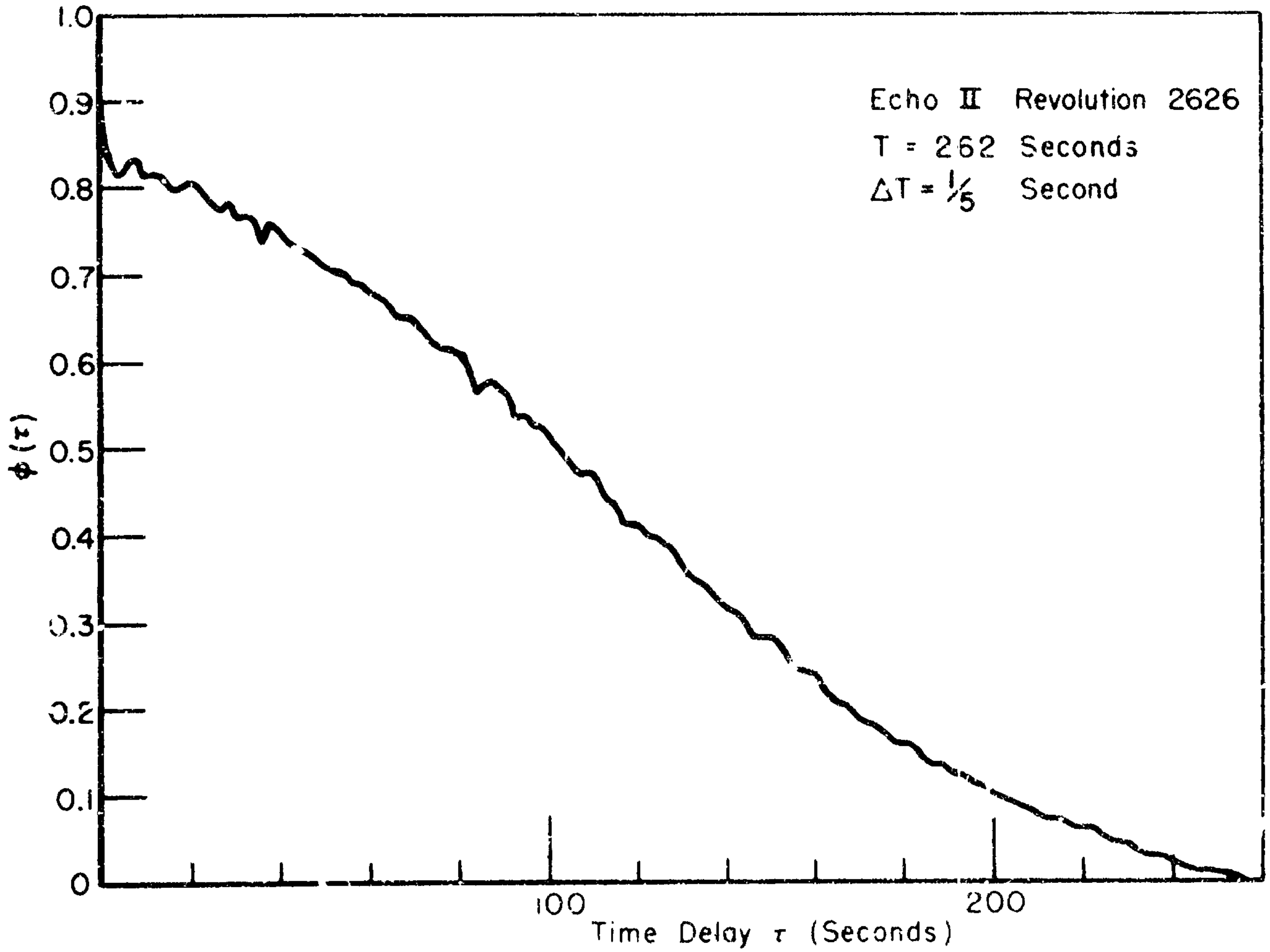

Fig. 3. The long-term autocorrelation function of Echo II-reflected signals.

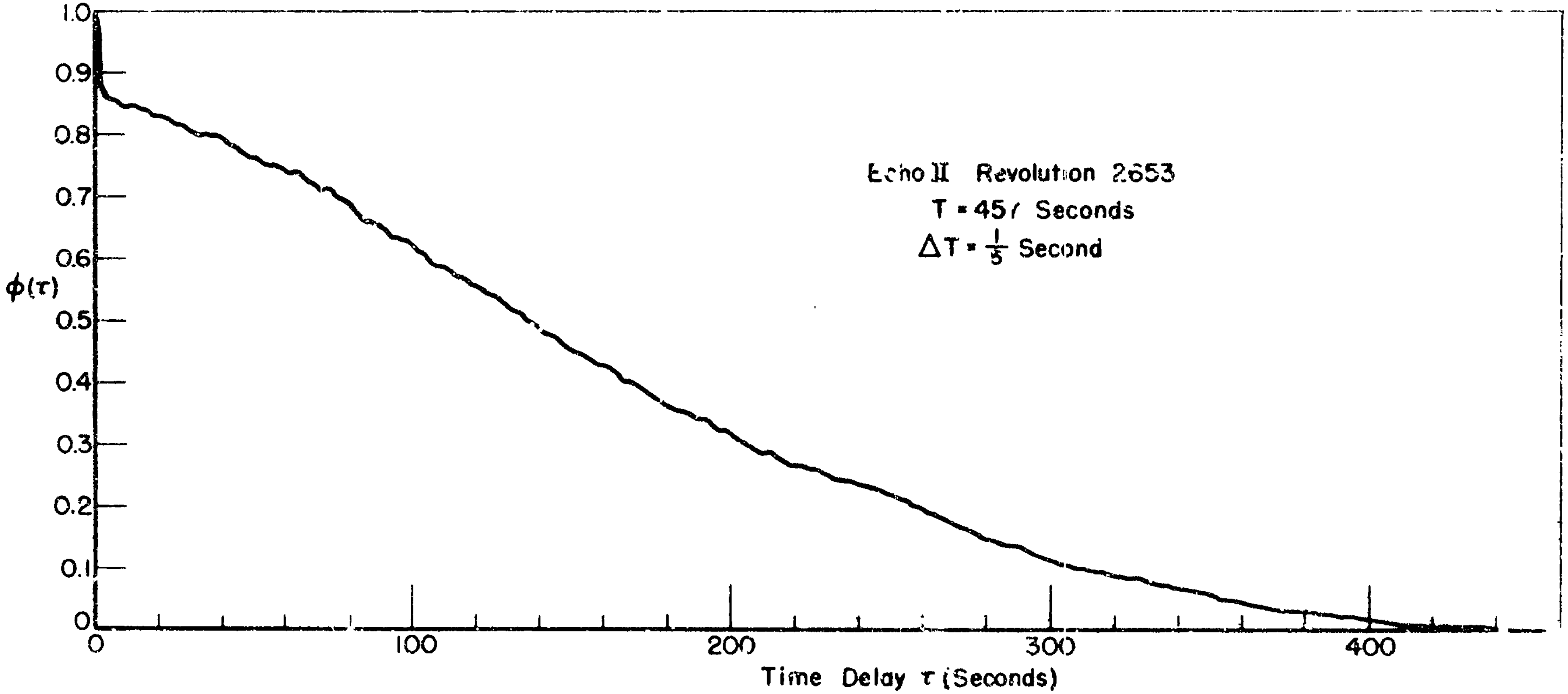

Fig. 4. The long-term autocorrelation function of Echo II-reflected signals.

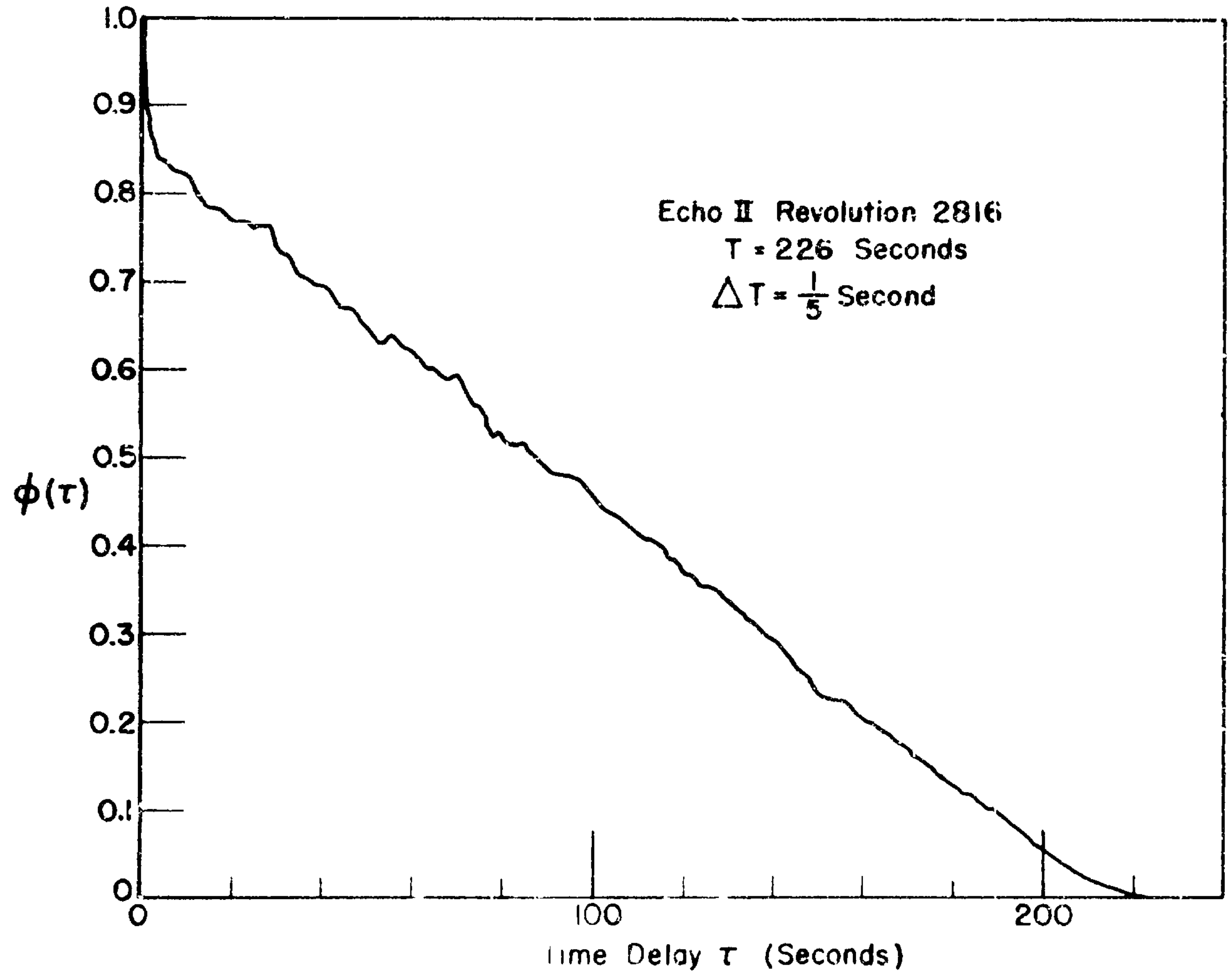

Fig. 5. The long-term autocorrelation function of Echo II-reflected signals.

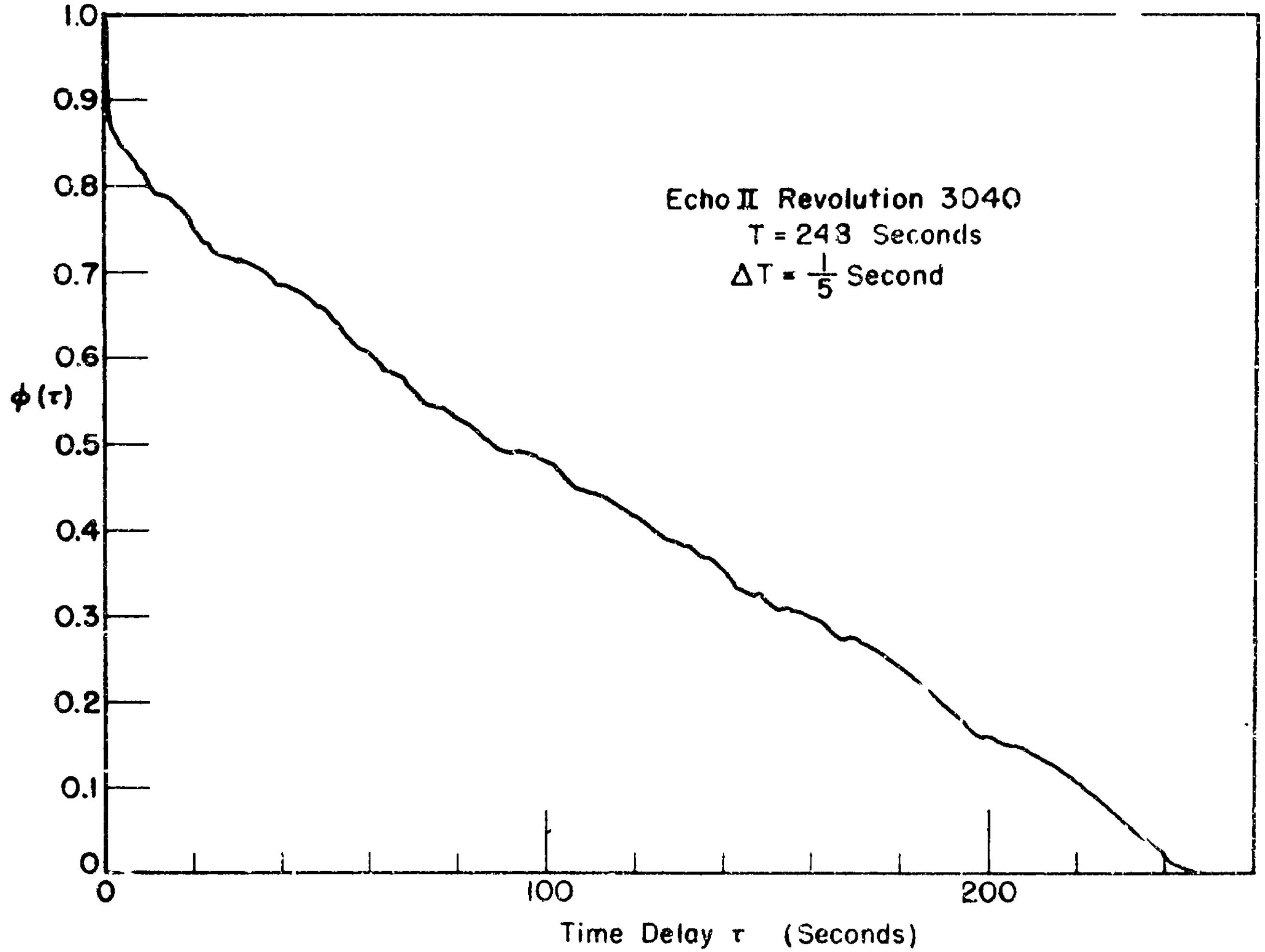

Fig. 6. The long-term autocorrelation function of Echo II-reflected signals.

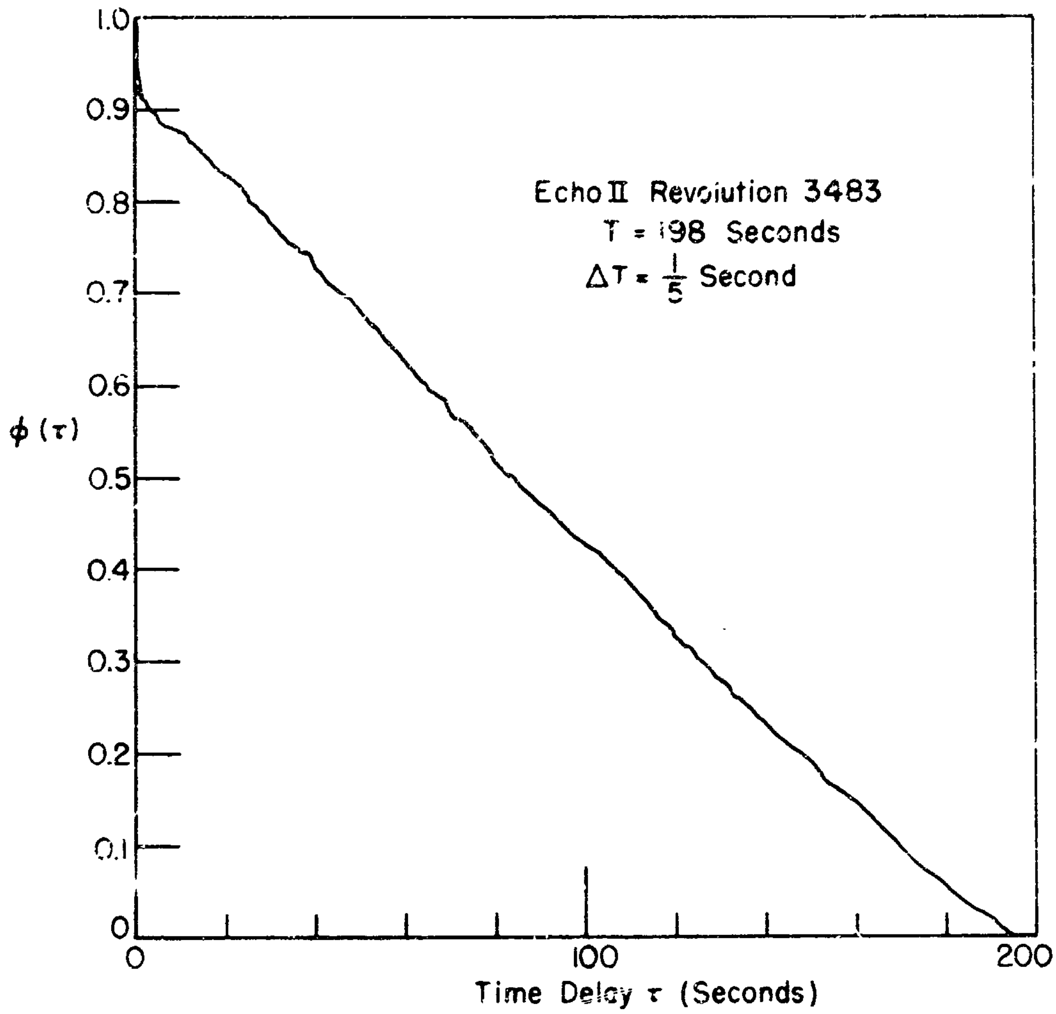

Fig. 7. The long-term autocorrelation function of Echo II-reflected signals.

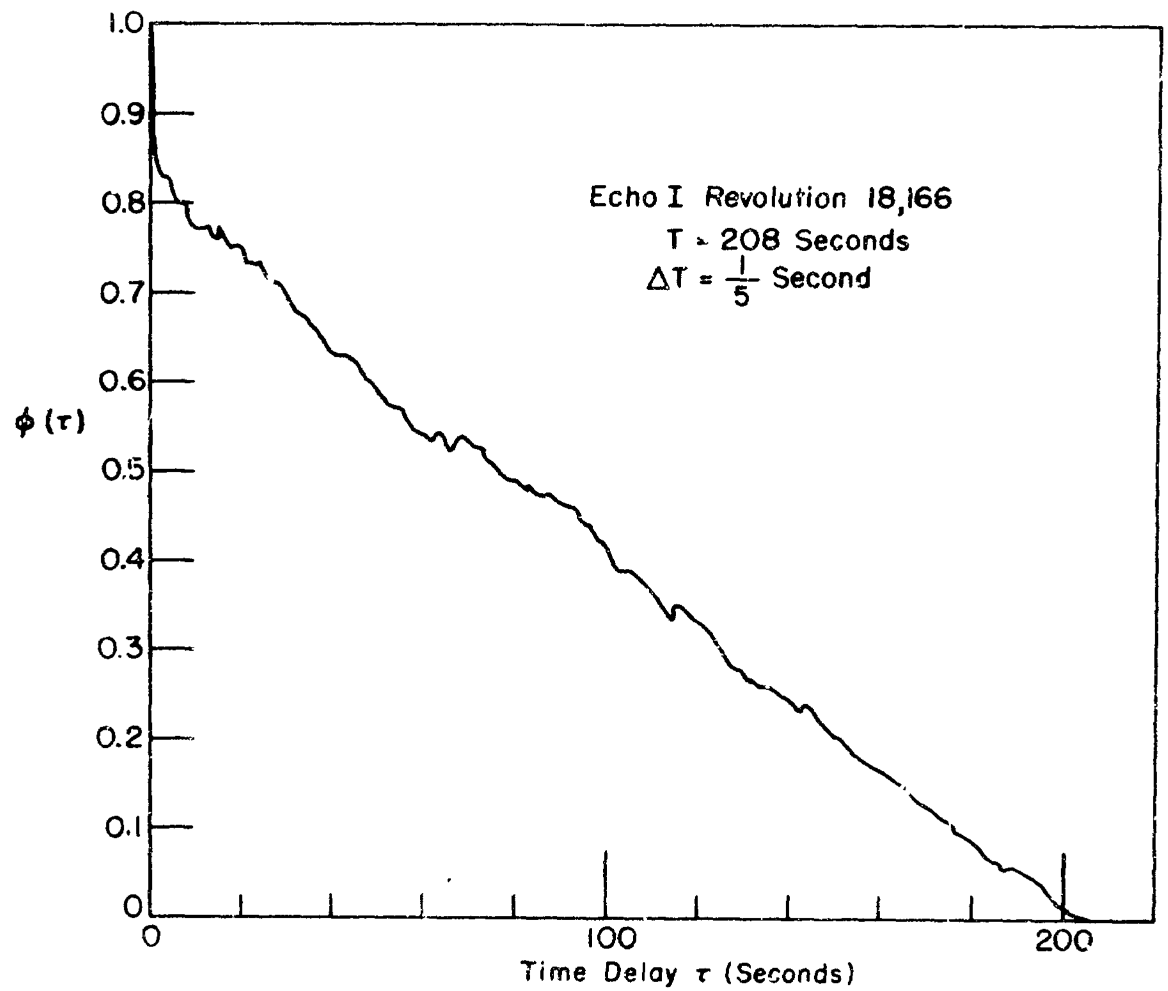

Fig. 8. The long-term autocorrelation function of Echo I-reflected signals.

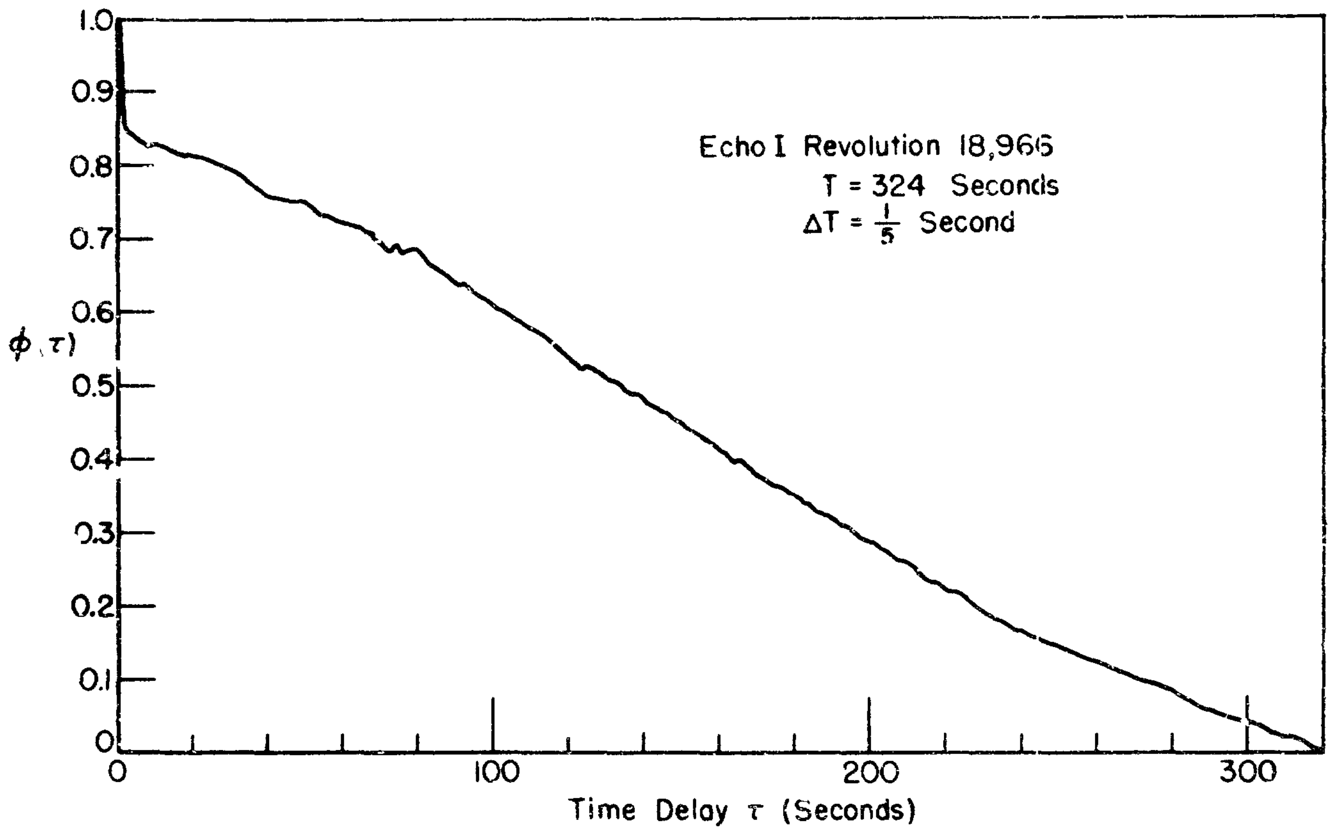

Fig. 9. The long-term autocorrelation function of Echo I-reflected signals.

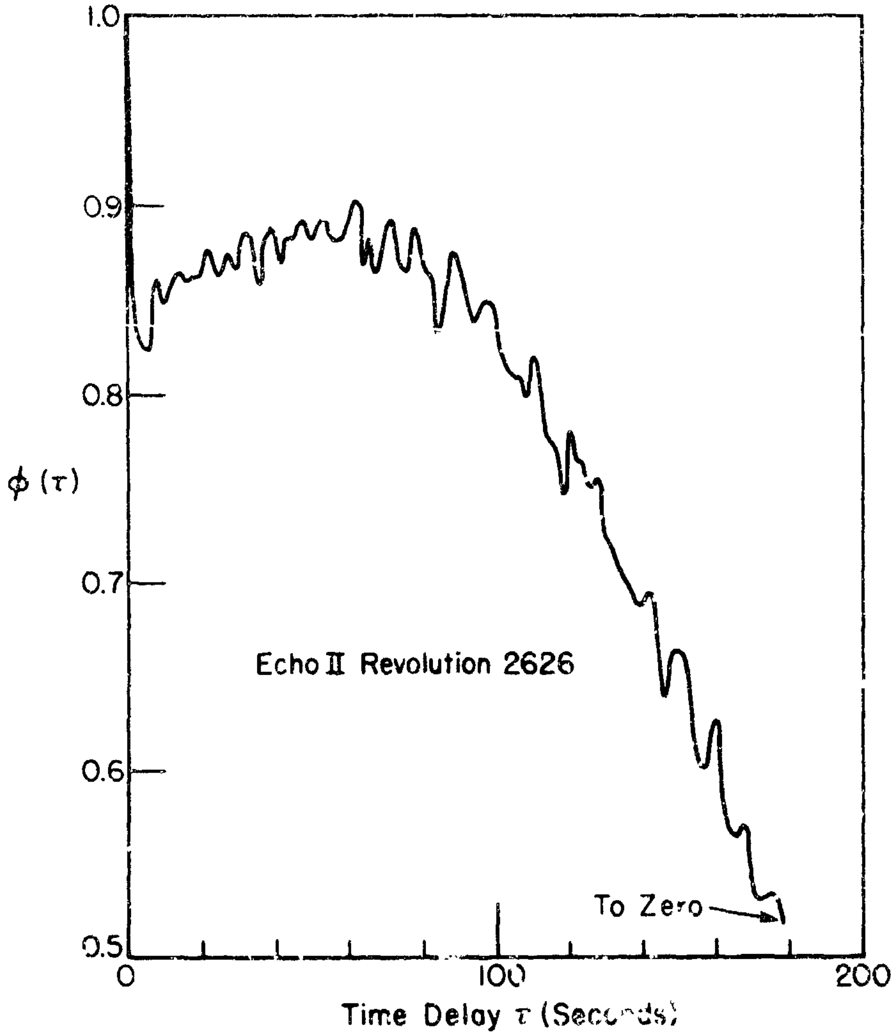

Fig. 10. The long-term autocorrelation function of Echo II-reflected signals. Triangular function removed.

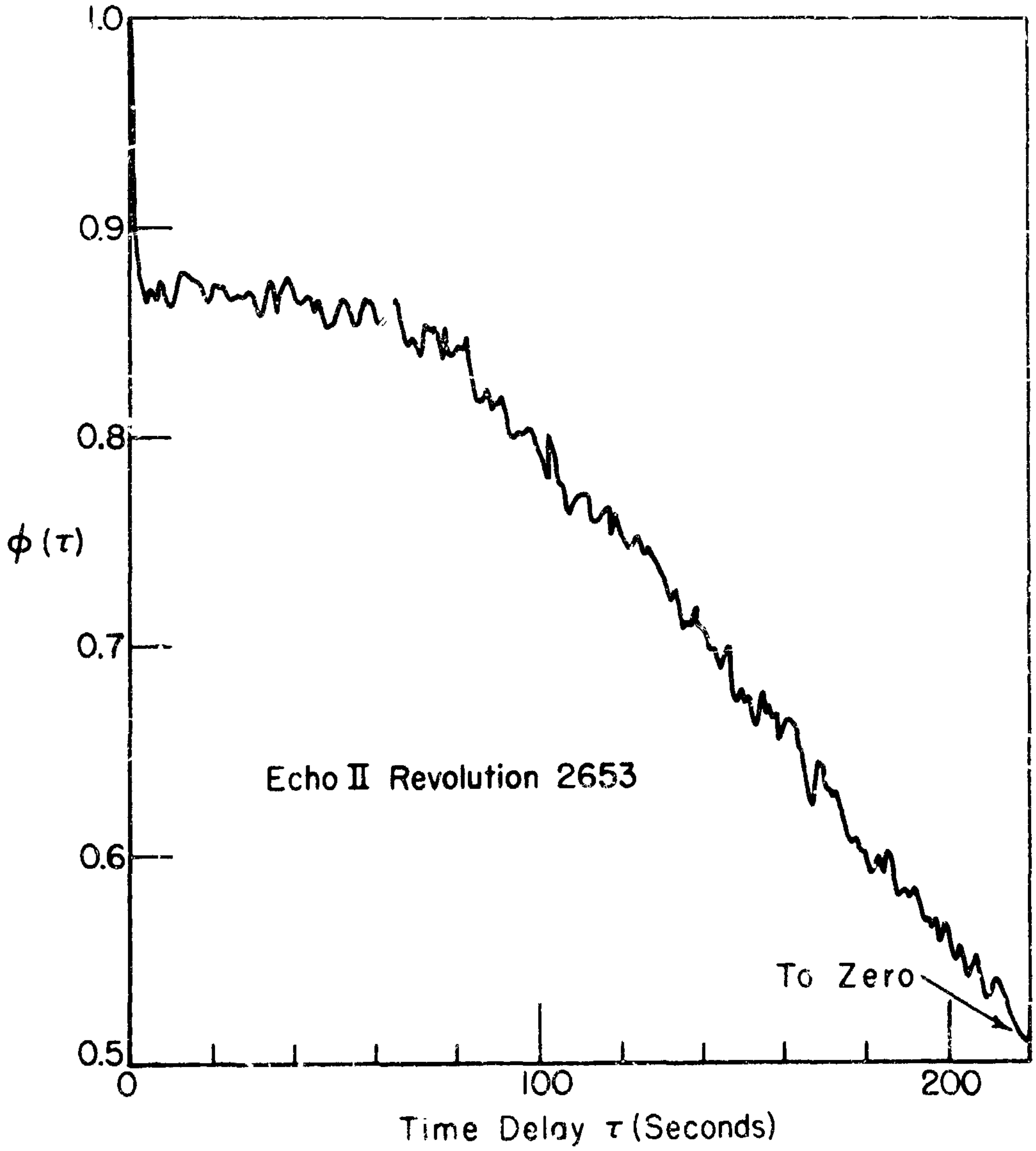

Fig. 11. The long-term autocorrelation function of Echo II-reflected signals. Triangular function removed.

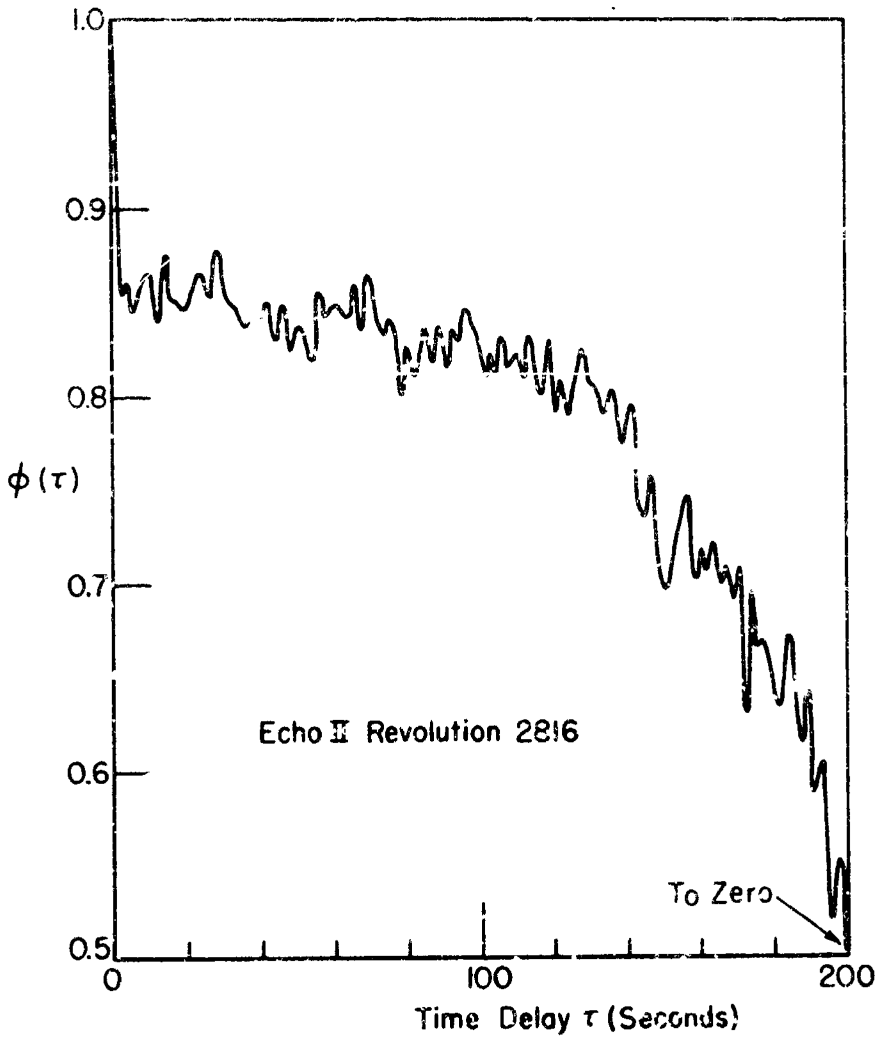

Fig. 12. The long-term autocorrel ti n function of Echo II-reflected signals riangul r function removed.

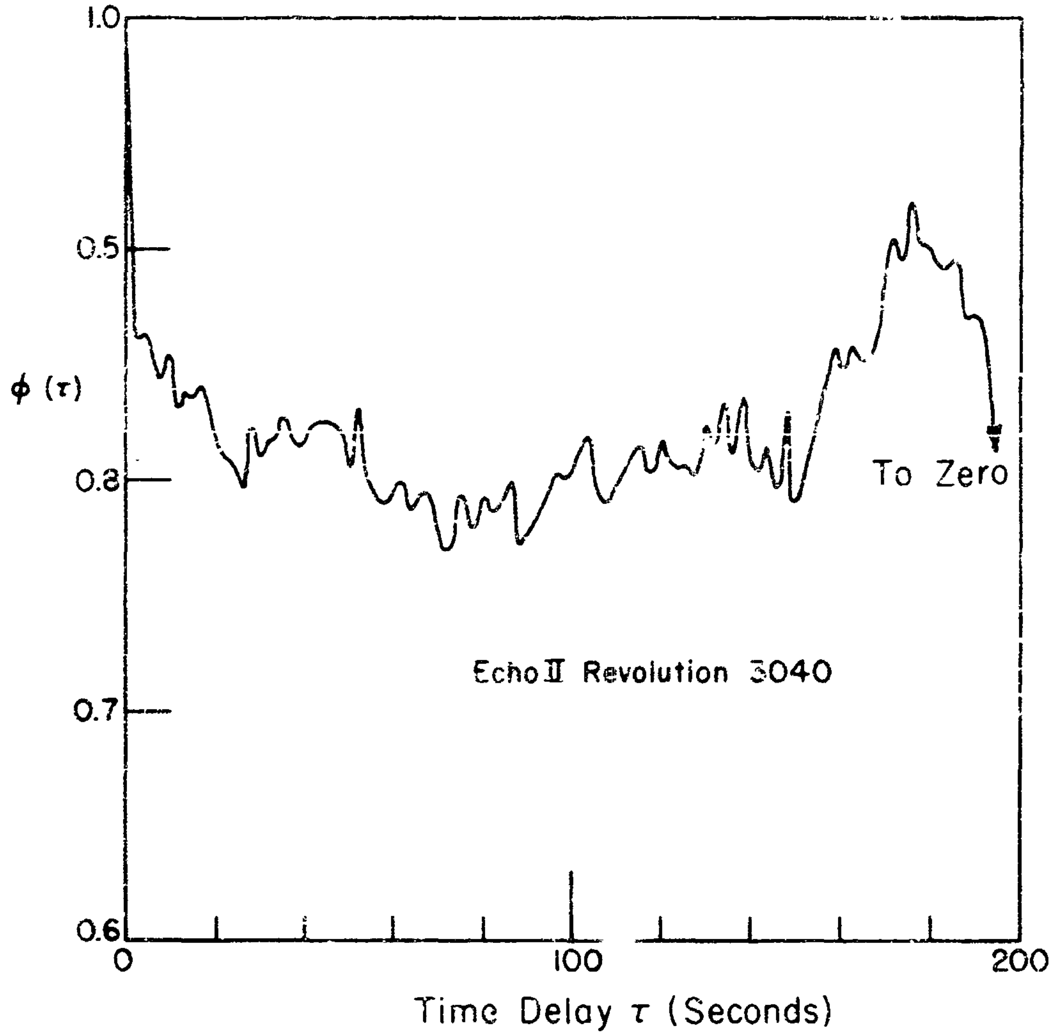

Fig. 13. The long-term autocorrelation function of Echo II-reflected signals. Triangular function removed.

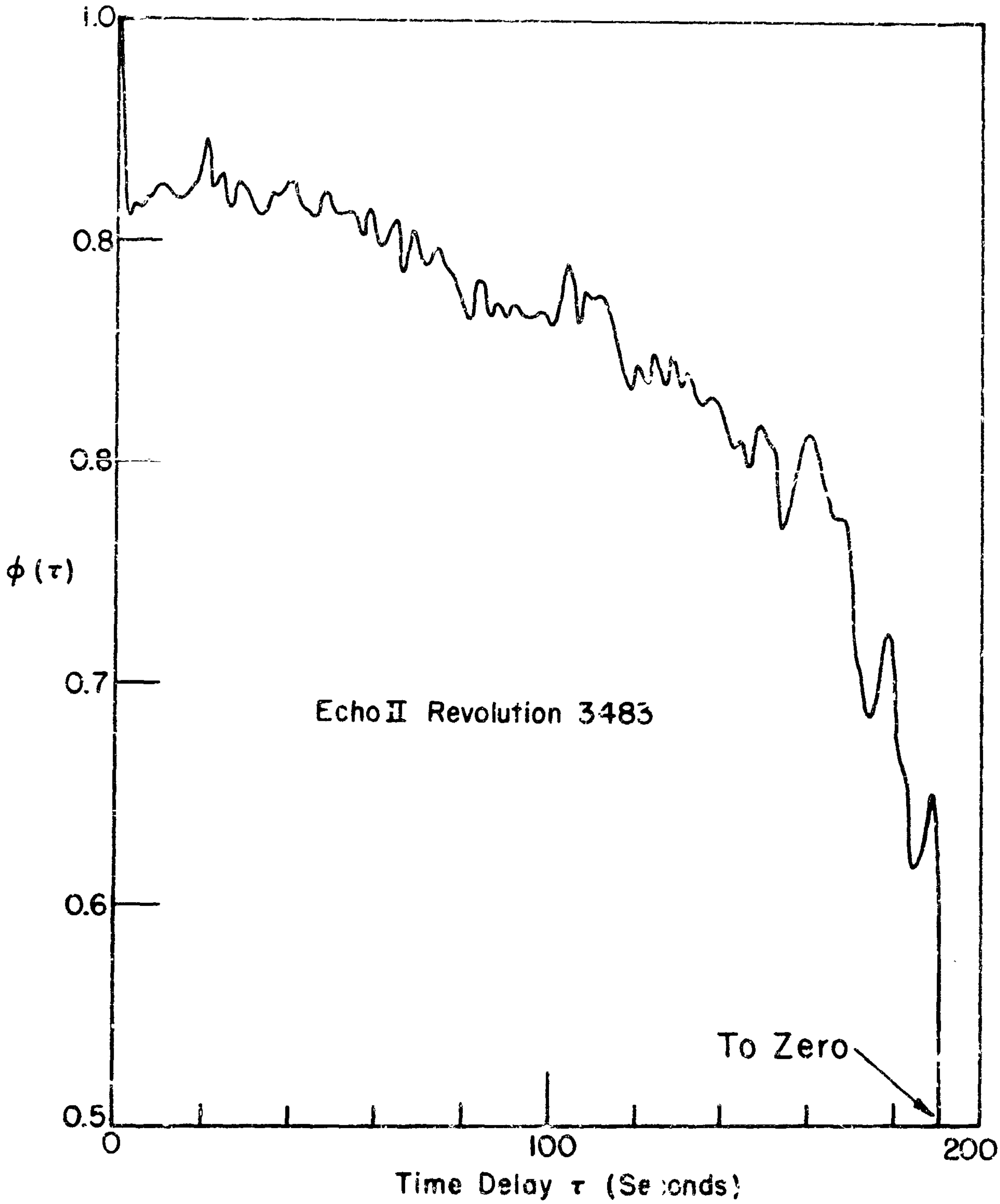

Fig. 14. The long-term autocorrelaticn function of Echo II-reflected signals. Triangular function removed.

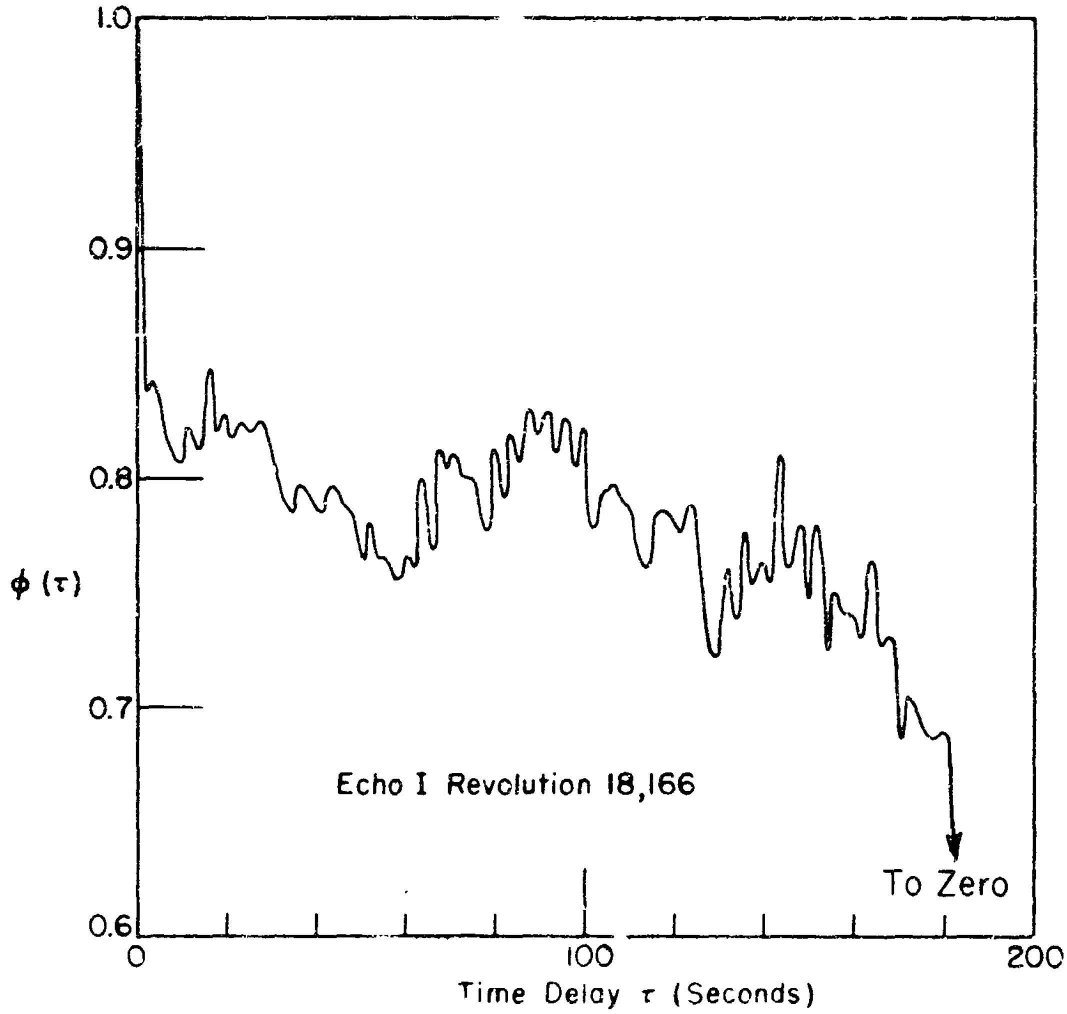

Fig. 15. The long-term autocorrelation function of Echo I-reflected signals. Triangular function removed.

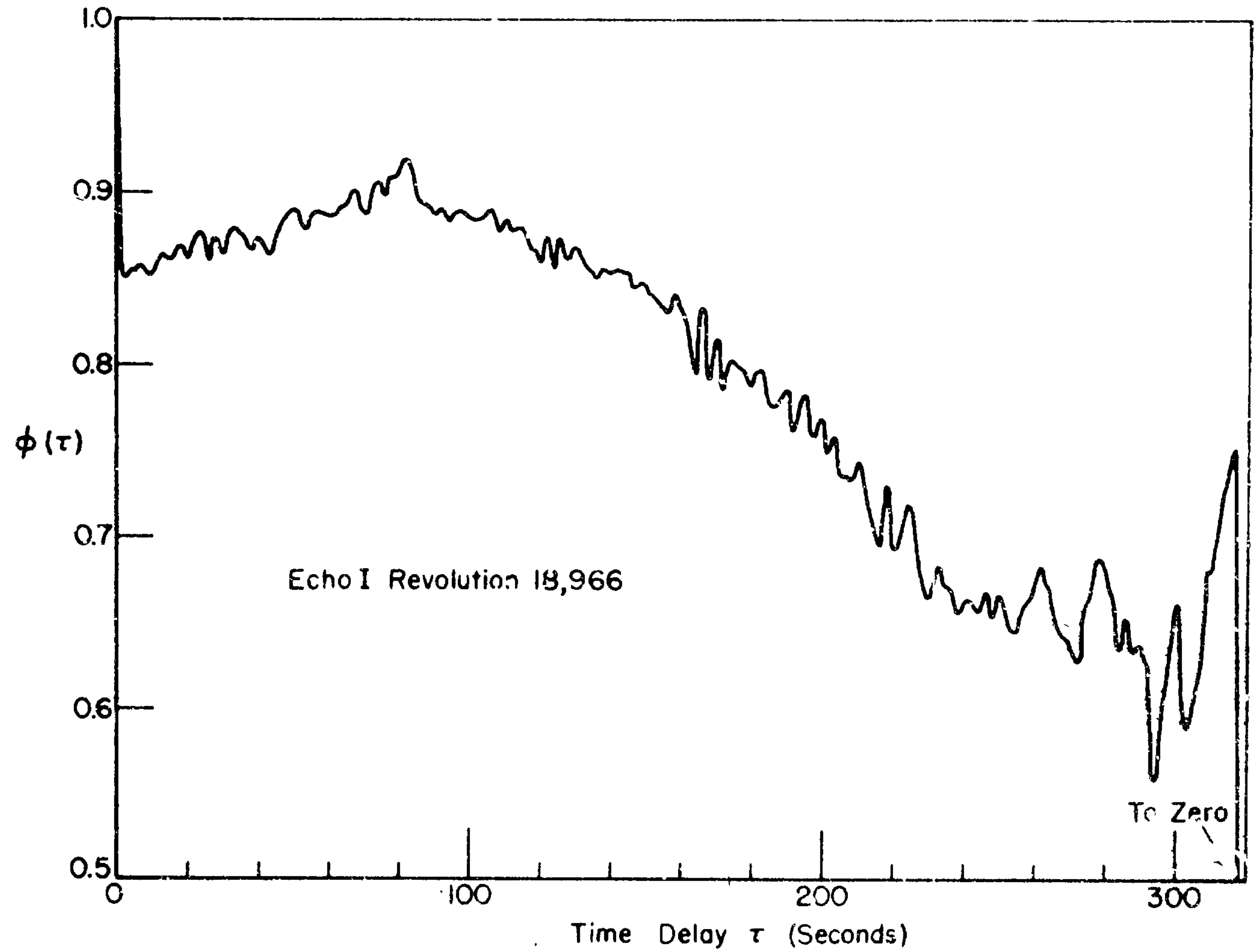

Fig. 16. The long-term autocorrelation function of Echo I - reflected signals. Triangular function removed.

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